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TEMPERATURE REQUIREMENTS OF HOT SPOT MANIFOLDS

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BY

C. S. KEGERREIS
AND
O. C. BERRY

BULLETIN No. 15
ENGINEERING EXPERIMENT STATION
LAFAYETTE, INDIANA

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BY

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PURDUE UNIVERSITY
LAFAYETTE, INDIANA
SEPTEMBER, 1923

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PREFACE

The information reported in this bulletin is a continuation of the results presented in a former publication "The Carburetion of Gasoline", Bulletin No. 5, together with the results of more recent investigations. As was stated in the previous bulletin, the hot spot method possesses certain inherent qualities that were worthy of continued investigation. The necessary quantity of heat being so easily available in the exhaust, the possibilities of its use for effecting good carburetion makes the subject of the necessary temperature in hot spot manifolds worthy of consideration. It is this fundamental information regarding necessary and available temperatures that can be used by the industry in developing more efficient and useful devices for securing good performance from automotive machinery.

The authors wish to express their appreciation for assistance rendered in the investigations and computation of the experiments to Mr. F. C. Hockema and Mr. J. W. Geiger, Research Assistants.

TEMPERATURE REQUIREMENTS OF HOT SPOT MANIFOLDS

I. INTRODUCTION

1. The Fuel Situation: The unprecedented increase in the use of the internal combustion engine, especially in its application to automotive purposes, has created such a demand for the more semi-voltatile petroleum fuels, that the problem of an ample continued supply is becoming acute. Approximately forty per cent of the United States natural petroleum resources have been consumed to date. The country is now using about eight per cent per year of the remainder. This situation calls for action. Previous research by the Carburetion Section of the Engineering Experiment Station has shown that it is possible by proper methods and equipment to effect a saving of at least twenty-five per cent over present average performance.

2. Method of Attack: The most obvious point of attack, both for better economy and for proper utilization of the less volatile fuels is by supplying heat from the exhaust of the engine to effect proper vaporization of the fuel used.

3. Preheating of Air: The method of introducing this heat by the air produces good economy, but included is an inherent capacity loss due to the change of the density of the charge, and the high cylinder temperatures produce increased detonation. The ordinary gasoline requires air temperatures of 150°F. for good operation and heavier fuels require much higher temperatures. With the average fifty-six degree Beaume′ gasoline, preheated air requires a temperature of 280°F. or a mixture temperature of 235°F. for a dry mixture in the manifold. In tests using a separately heated hot spot the data has shown the dry point is reached with air at 150°F. under the same flow rate as before. Thus an increase of power capacity has been effected by increasing the charge density and so the volumetric efficiency.

4. Information Needed: It has been shown that good carburetion by localized or "hot spot" heating can be attained without excessive heating of the charge and consequent reduction of power available but little satisfactory data is available for the specific requirements of the fundamental "hot spot" especially when heated by the exhaust gases. The investigation briefly described in this bulletin was undertaken to supply the much needed information on the temperature requirements of the hot spot manifold and the temperatures available in the engine exhaust. The investigations were divided into two general lines:

1. The temperatures required for vaporization of different fuels at high rates.

2. The temperatures available in the exhaust under dif-

ferent running conditions. The results of these two researches should then enable the engineer to properly design a manifold to utilize any possible fuel.

II. THE HOT PLATE TESTS

5. Object of Hot Plate Investigation: Before a "hot-spot" manifold can be designed for any fuel, it is necessary to determine three points.

1. The rate of vaporization per unit area for different fuels at various temperatures.

2. The temperatures at which the vaporization characteristics are most suitable for the purpose.

3. The point of deposition of solid matter.

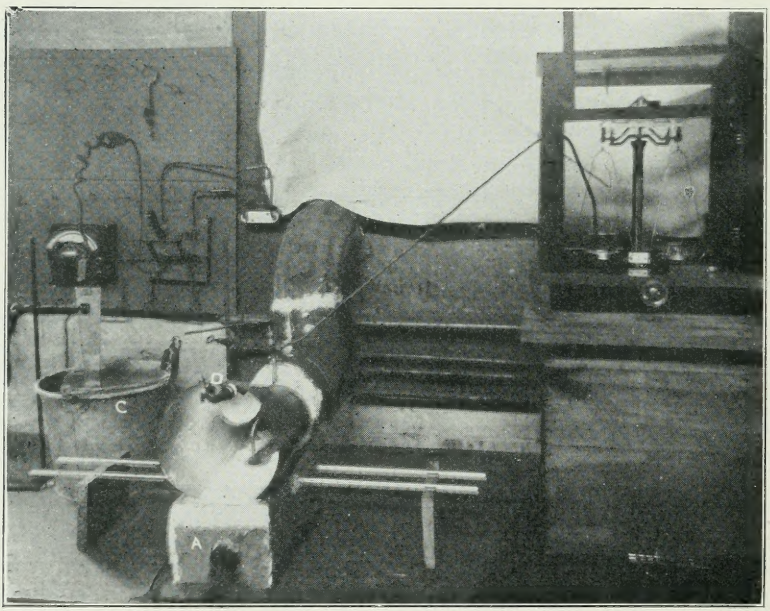

Fig. 1. Hot Plate Apparatus

6. Description of Test Apparatus: A general view of the apparatus used in these tests is shown in Fig. 1. Fig. 2 is a detailed view of the iron plate with the shallow fuel well, and Fig. 3 the same for the plate with the deeper well. The apparatus is made up as follows: An iron plate 5/8 inch thick by 4 by 8

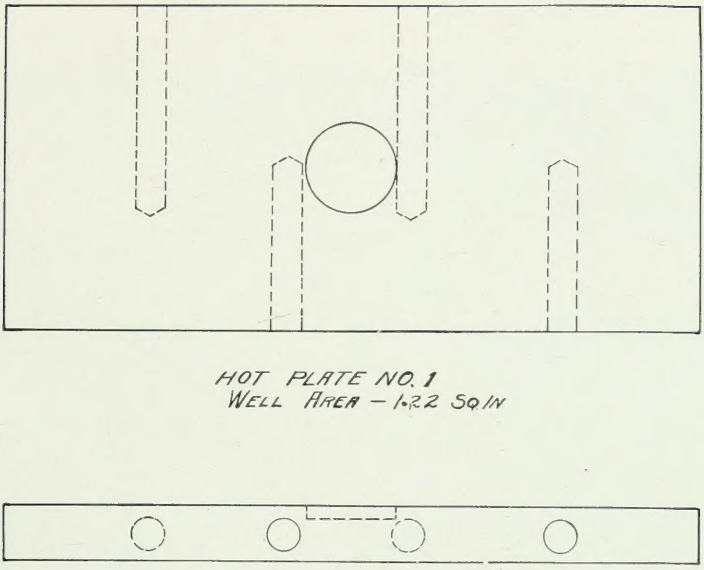

Fig. 2. Hot Plate No. 1

inches was placed over an electrical heating element and packed in a box filled with asbestos. (A, Fig. 1). At the top center of the plate, (B, Fig. 4), was a well 1.015 inches in diameter by 0.128 inches deep, (Fig. 2); an electric light bulb, (D, Fig. 4), serves to illuminate this well. Two thermometer wells were drilled on each side of the plate, one of each pair being as close as possible to the vaporizing well and the other farther away to give the plate temperature at a point where there was little or no flow of heat toward the evaporating fuel. The heat was regulated by a salt water rheostat (C, Fig. 1) in series with the heating coil, ammeter and switch. The vaporized fuel was carried away through a hood over the plate connecting with an eight-inch vertical pipe. The gasoline was weighed on a small chemist's balance, the fuel being siphoned from a beaker on the scale through a small copper tube to a point one-half inch above the top of the well. The flow of fuel was regulated by a needle valve placed in the line just outside of the hood. The temperatures were measured by 950° F. nitrogen filled mercurial thermometers, (E, Fig 4), accurate to within five degrees at the highest temperatures. Time was taken with a manually operated stop watch.

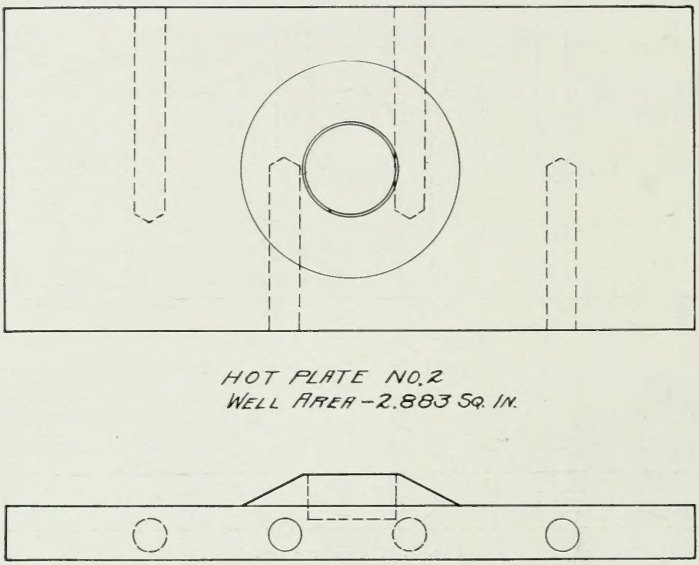

Fig. 3. Hot Plate No. 2

7. Improved Vaporizing Well: It was found that a portion of the fuel was thrown out over the edge when the shallow well (Fig. 2) was used, so that too high a rate of vaporization per unit area was indicated. To remedy this in the later tests the vaporizing well was made deeper by welding additional metal around the top of the well, (Fig. 3), which gave a final size of 1.051 inches diameter with a depth of 0.610 inches. The vaporization rate indicated by this well was too low for the following reasons: The iron forming the upper part of the well (Fig. 3) was farther away from the heating element than the thermometers were, and was consequently lower in temperature. This resulted in a slower vaporization from these upper portions. The entire wetted area was measured as the vaporizing surface, so the average rate of vaporization was lower than it would have been, had the entire surface been at the temperature indicated by the thermometers. Since the results obtained from the first well tended to be too high, and those from the deeper well too low, an average between the two was used.

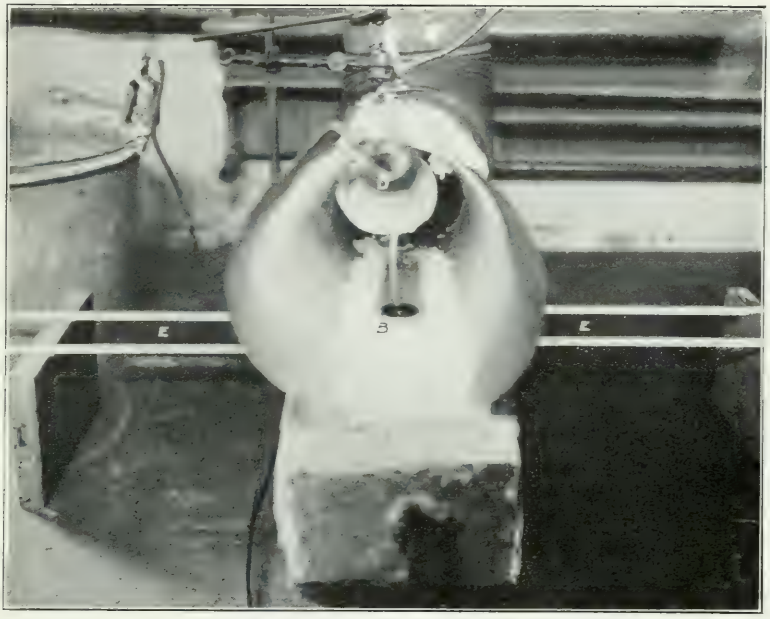

Fig. 4. Thermometers in Hot Plate

8. Calibration of Apparatus: The siphoning correction is small and is equal to the weight of gasoline displaced by the fuel pipe between the initial and final levels of the fuel in the beaker, the pipe being considered as a solid. The error is 0.88 per cent for the individual beaker and pipe used, and was corrected in the computation of the tests. The evaporation of the fuel from the surface exposed in the beaker will vary according to the saturation of the air in the scale box. The temperature of the air above the beaker was recorded for each series of tests and from calibration tests this error was corrected with a considerable degree of accuracy.

9. Fuel Tested: Three gasolines and one kerosene were tested. The gravity and distillation data are shown in Table 1. These fuels were obtained directly from a refinery through the courtesy of one of the leading distributors of petroleum fuels.

Table 1.

Distillation of Hydrocarbon Fuels.

Percent Distilled	Gravity of Fuel—Beaumé Scale			
	70	64.2	56.5	41.5
Initial Boiling Point.	97°F.	120°F.	96°F.	346°F.
10	127	155	162	386
20	143	169	210	400
30	155	179	247	408
40	165	187	272	413
50	176	196	295	424
60	187	205	313	432
70	193	215	335	440
80	206	227	356	452
90	225	245	381	476
Maximum	300	312	425	524

10. Value of Distillation Data: The distillation data of a fuel is very valuable, as the temperatures at which the fractions distill, form the criterion by which comparisons of different fuels for volatility should be made. The gravity is a very uncertain indication of quality, as several combinations of petroleum fractions may have the same gravity and yet be quite different fuels. The limiting points and boiling temperatures of the fractions more than the gravity, indicate the character of the fuel.

11. Method of Conducting Tests: In conducting a test on the hot plate the current was switched on the heating coil and the plate heated gradually to a point of vaporization of the fuel in the well. This point varies with different fuels. In the meantime, the depth of fuel in the well was adjusted so that when the correct temperature was attained, the rate of heat conduction was steady and the temperature constant.

When the temperature and wetted area in the well were properly adjusted, the beaker on the scale pan was filled, the weights made ready and the beam let down on the knife edges. When the beam came to a balance, the stop watch was started. Weights equal to the weight of fuel to be used during the tests were then removed from the pan and attention centered on the control of the liquid level in the well and recording the temperature of both the plate and in the scale box. As the beam again balanced the watch was stopped, thus completing the test.

12. Constant Condition in Test Required: A long period of preliminary testing emphasized the necessity of maintaining constant conditions for a period previous to the starting of a test. This applied to the temperatures of all parts of the apparatus as well as to the evaporation of the liquid. When fresh gasoline was first introduced into the hot well, its rate of vaporization was high, as the more volatile portion evaporated first and left the heavier parts as a comparatively inert mass in the

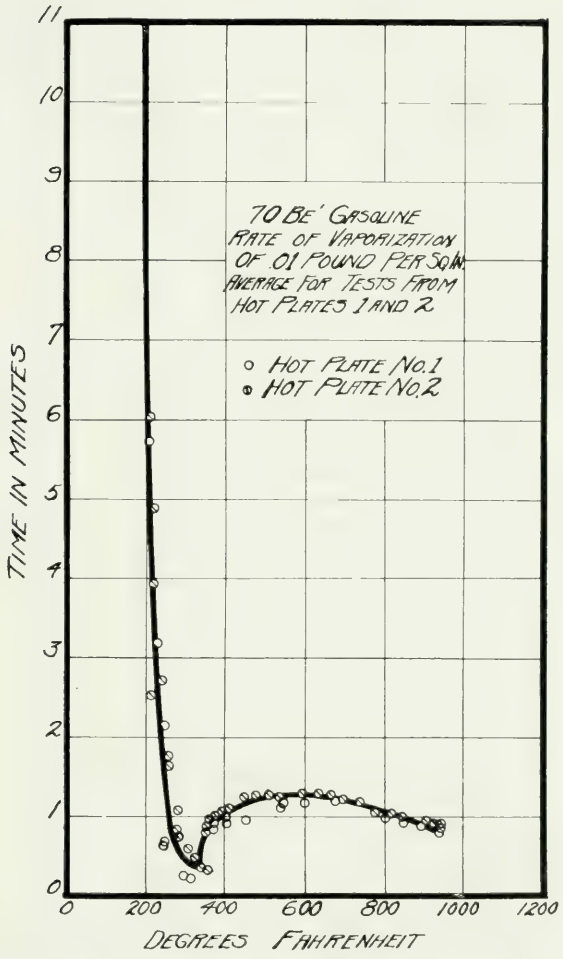

Fig. 5. Vaporization Rate, 70 Beaumé Gasoline

hot well. After a time, however, a state of equilibrium was reached when the gases leaving the hot well contained the same proportions of the lighter and heavier fractions as the entering gasoline. This gave the proper rates of vaporization and are those reported and shown in plotted curves, Figs. 5 to 9.

13. Peculiarities Under Test Conditions: In the state preceding that of the spheroidal, the liquid boiled violently at all excepting lower temperatures. At any point in this state preceding that of the spheroidal, there was a tendency for a thin

film of liquid to seep over the edge of the vaporizing well. When the ebullution became violent, small drops were thrown over the edge and vaporized from the face of the plate. This is the period of the most rapid vaporization and corresponds to the lowest portion on each of the curves and the points on this part of the curve are therefore only approximations. When the temperature was high enough to throw the fuel into the spheroidal state, the depth of fuel was decreased, especially when using the deeper well, to prevent small globules from being thrown out of the

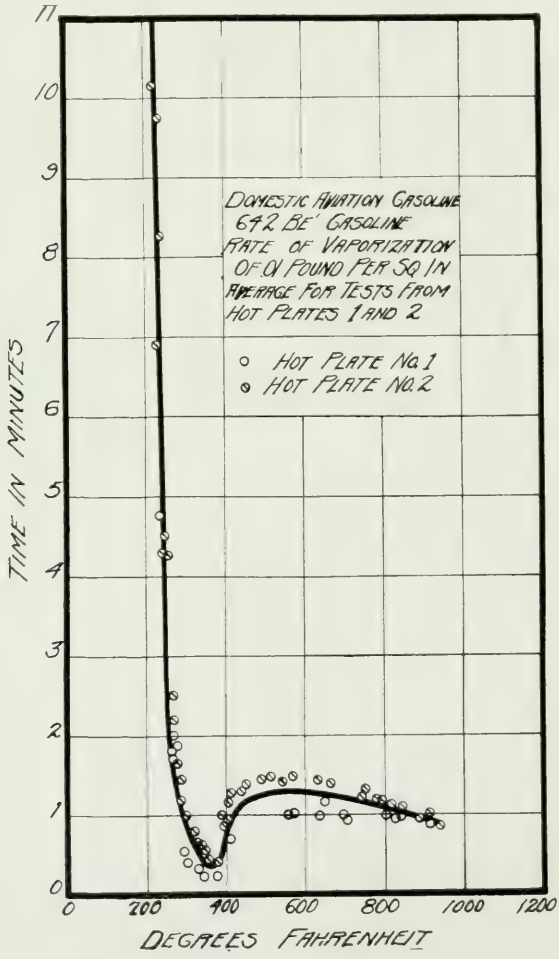

Fig. 6. Vaporization Rate, 64.2 Beaumé Domestic Aviation Gasoline

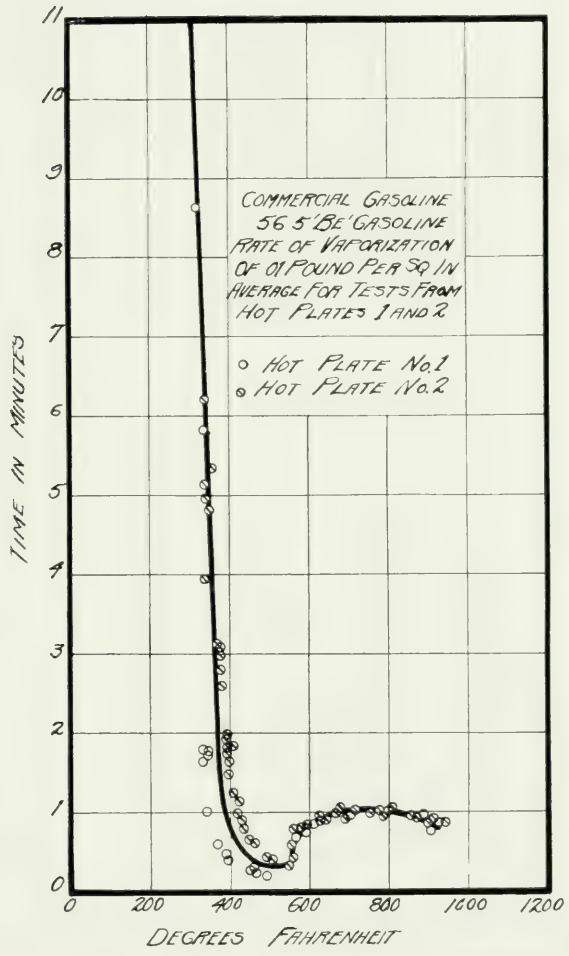

Fig. 7. Vaporization Rate, 56.5 Beaumé Commercial Gasoline

bubbling mass. A fuel depth of .177 inches proved sufficient to prevent this spill over and was used in all cases when the fuel was above its minimum spheroidal temperature.

14. Results of Tests: The results of the tests were shown in Figs. 5 to 9 inclusive. In these curves the temperature, Fahrenheit, is plotted horizontally and the vertical ordinate shows the time in minutes required to vaporize one hundredth of a

pound of fuel per square inch of hot surface. The temperatures are in all cases those indicated by the thermometers in the plate nearest to the hot spot. The curves in Figs. 5 to 7 show the gasoline series and the average of the results for the two plates. The 70° Beaume′ gasoline results are presented in Fig. 5, the domestic aviation or 64.2° Beaume′ gasoline in Fig. 6, and the commercial or 56.5° Beaume′ gasoline in Fig. 7. In all these plots there are a majority of the points shown above the curves. This is because the plotted points represent two distinct series

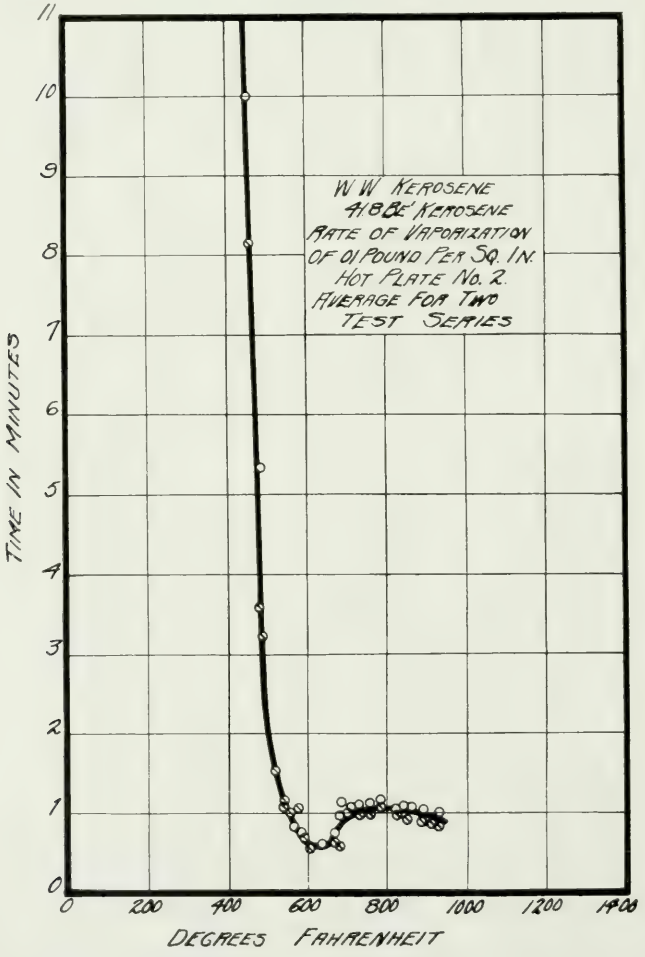

Fig. 8. Vaporization Rate, 41.8 Beaumé W. W. Kerosene

of tests and the curves are intended to represent the two series, rather than the individual tests comprising them. The curve values may, therefore, be taken to represent the vaporization from Hot Plate No. 2, as determined from two checking series of experiments. The curves are similar in their general characteristics, the difference being that increasingly high temperatures are necessary to vaporize the less volatile fuels in the spheroidal state. This is especially noticeable in Fig. 8, which shows the vaporization of 41.5 Beaume' kerosene. The significant results as indicated in Figs. 5 to 9, are discussed in the following paragraphs.

15. Deposition of Solids: During the period of rapid boiling the fuel showed a deposit of solid matter which was left on the edges of the well. The two lighter gasolines, the 70 and 62.4 Beaume' left a deposit that resembled paraffin, while the deposit from the sample of 56.5 Beaume' gasoline and the kerosene had more the appearance of tar or asphalt. When the liquid film was allowed to seep over the edge of the well, these deposits were dissolved and carried out with the vapor. This vapor often re-deposited some of the solid matter in the hood behind the well. (See Fig. 4). When the spheroidal state was reached the deposition of solid matter ceased entirely. This is very important to the designer of a hot-spot manifold. The temperatures that cause a deposition of solid matter are rather limited in extent and are entirely below those that will throw the fuel into the spheroidal state. The high temperatures are not the ones that cause the clogging of the manifold.

16. Relation of Spheroidal State to End Point: The temperature at which the fuel enters the spheroidal state in relation to the end point is of interest. The end points for the four fuels are 300°, 312°, 425° and 524°F., the lightest fuel being named first. The spheroidal points in the same order as above are 350°, 390°, 520°, 620°F. Thus the spheroidal state does not occur until well after the end point of the fuel has been passed.

17. Dryness of Vapor: The appearance of the vapor under different conditions was interesting. When the liquid was boiling from a wetted surface the vapor was quite wet and condensed easily and in fact as it was carried to the rear of the hood, it appeared like a dense fog. In the spheroidal state the vapor was dry and almost invisible so that even after it had traveled several feet in a cold pipe no appreciable condensation could be noticed.

18. Range of Useful Temperatures: The curves in Fig. 9 show that the effectiveness of the hot spot drops off very rapidly at the lower end of the temperature range. A similar curve for the fuel to be used will show the lowest temperature it is

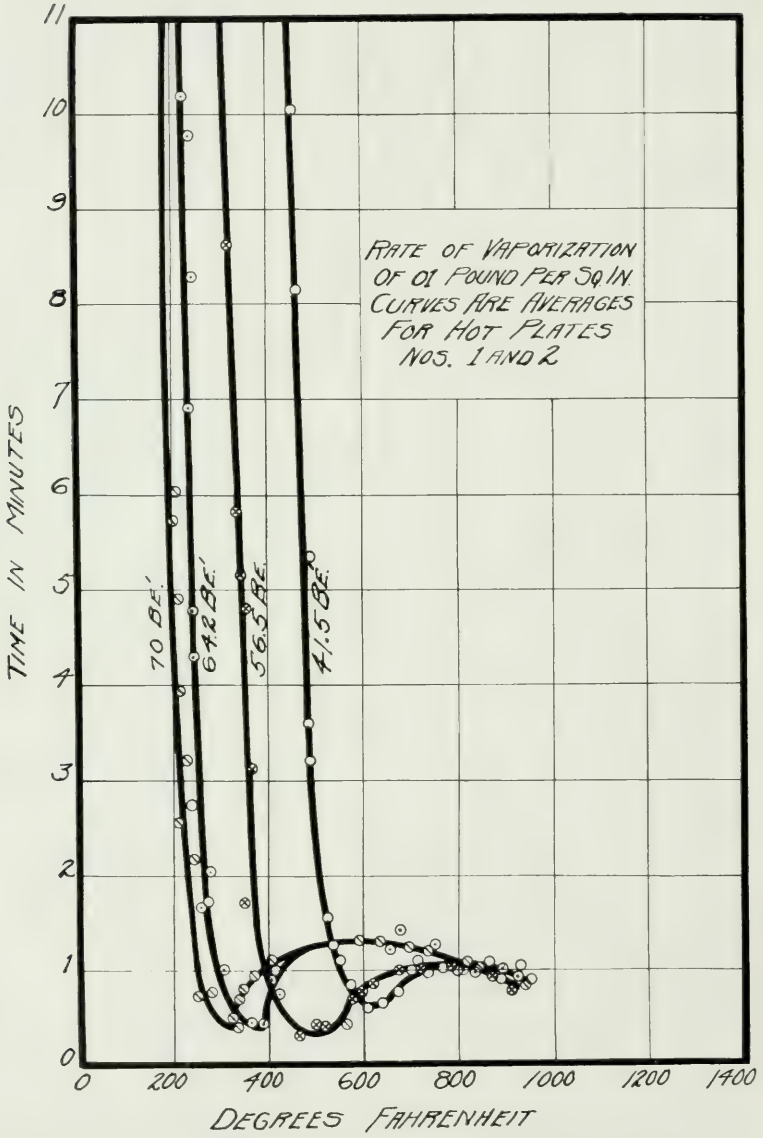

Fig. 9. Vaporization Rate, Summary of Four Fuels Used

advisable to use with that fuel. It is not wise to attempt to make use of the very highest rate of vaporization for two reasons. The temperature range is too narrow and this is where the deposition of solid matter takes place. It is better to use the higher temperatures that produce the spheroidal state. After the spheroidal state is once reached an increase in temperature does not make any very great change in the rate of vaporization. The metal in the hot plate was cherry red in a few tests, but at no time were the fumes from the hot spot ignited by the plate when the latter was below 1460°F. It is thus practical to use a very wide range of temperatures in the metal of a hot spot, and without the necessity of using a thermostat.

III. EXHAUST GAS TEMPERATURES

19. Factors Influencing Exhaust Temperatures: The second group of tests were intended to determine the exhaust gas temperatures of an automobile engine under different running conditions. Some very careful work has previously been done by several investigators to determine these temperatures under

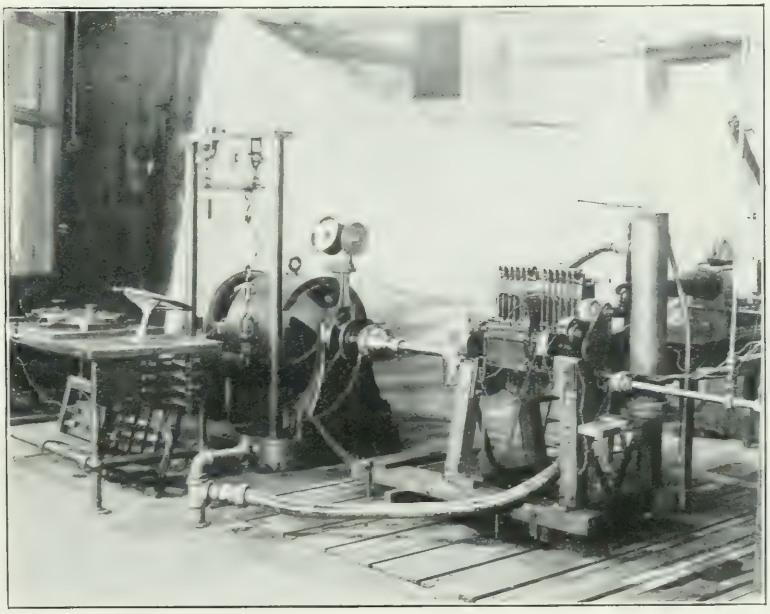

Fig. 10. General View of Testing Plant

specific running conditions, but little attention has been given to evaluating the factors influencing them. The following list points out the more important factors which might have an influence on the temperature of the exhaust gases.

(a) The temperature of the cooling water.
(b) The temperature of the inlet air.
(c) The timing of the ignition.
(d) The richness of the fuel mixture.
(e) The speed of the engine.
(f) The load carried by the engine.

Tests were therefore carried out to determine the effect of each of these factors on the temperature of the exhaust gases.

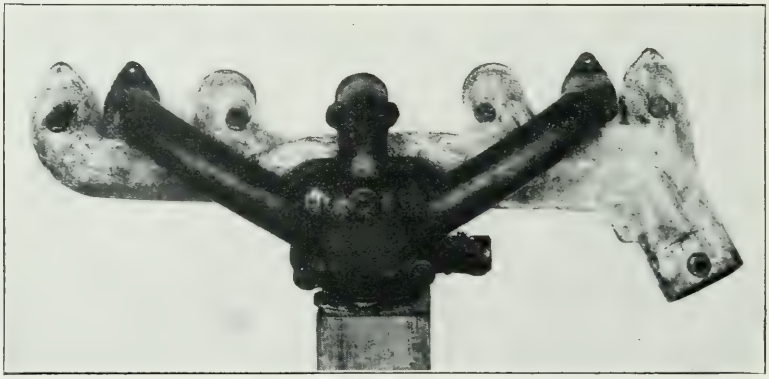

Fig. 11. Manifold No. 1

20. Description of Apparatus:

(a) Engine. The apparatus used was an Oakland-Northway Six-cylinder Engine, having a 2 13/16 inch bore by a 4¾ inch stroke, mounted on the test block, Fig. 10, and connected to a Diehl electric dynamometer.

(b) Manifolds. Two manifolds were used, designated as Manifolds No. 1 and 2. These are shown in Figs. 11 and 12. Manifold No. 1 had the early conventional type of hot spot, obtained by passing a very small portion of the exhaust gases around the exterior of the three headers of the intake manifold. Manifold No. 2, has the intake cast on top of the exhaust and has enough contact between the two headers to allow a large flow of heat. The manifolds were interchanged for some of the tests.

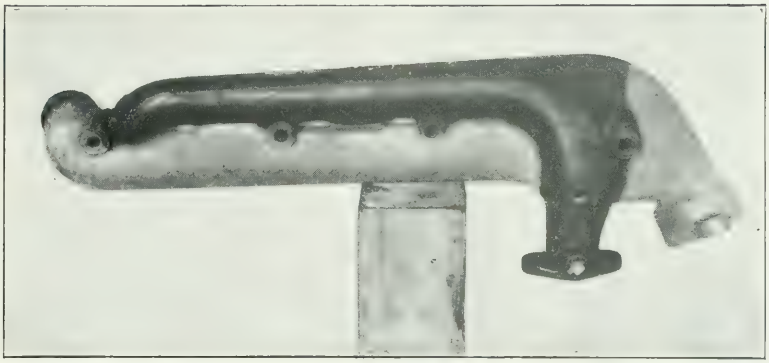

Fig. 12. Manifold No. 2

(c) Air Measurement. The air was measured by an Emco No. 4 diaphragm meter reading to cubic feet, the dial being so arranged that an accurate estimation to tenths was possible.

(d) Fuel Measurement. The gasoline was siphoned from a two litre beaker on a large chemists' balance, Fig. 13. Due to the siphoning of the gasoline an error was introduced in the weighing equal to the weight of the fuel displaced by the length of pipe between the initial and the final fuel levels in the beaker, the pipe being considered a solid. This error was corrected by increasing the weights by an amount equal to weight of gasoline displaced by the pipe.

(e) Speed Measurement. The speed was kept constant by using a tachometer on the dynamometer and determined by the stop watch and revolution counter readings. In order to start and stop the measurement of certain quantities at the same instant, the watch, revolution counter and air meter were electrically controlled by the scales. They were started and stopped by the scale beam balancing and closing a circuit through nickel wires dipping in mercury cups, and operating electro magnets, Fig. 13.

(f) Brake Load. The brake load was measured by a set of Fairbanks scales reading to a tenth of a pound, the scales being integral with the dynamometer.

(g) Ignition Timing. The ignition timing was determined by the apparatus shown in Fig. 14. A small gap was left between the revolving pointer and stationary disc. The disc was marked

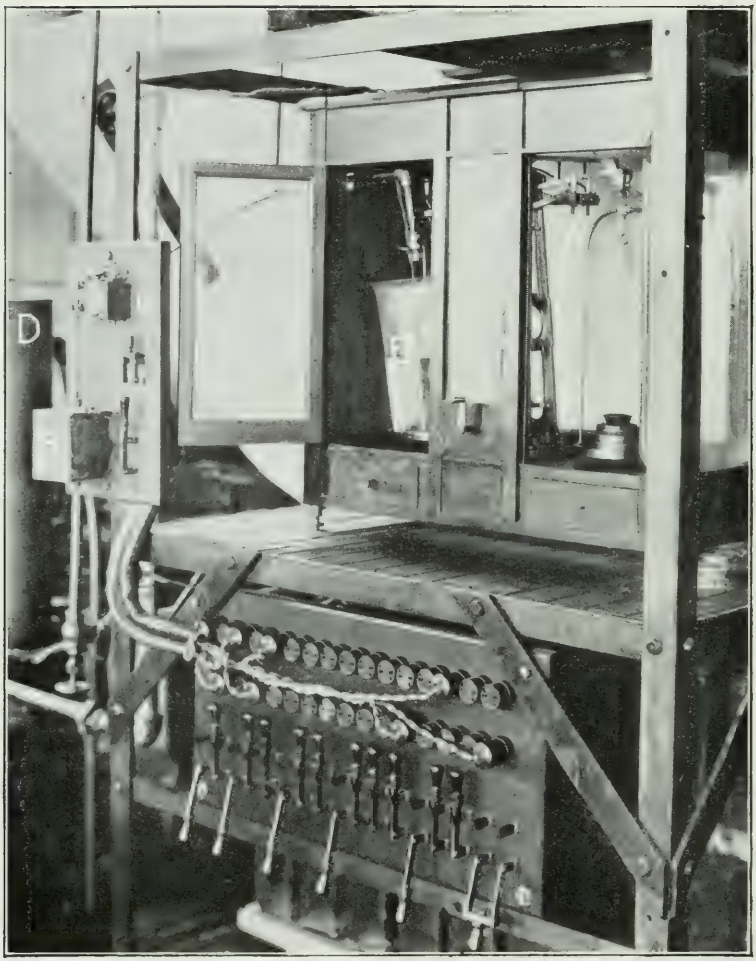

Fig. 13. Fuel Balance and Electric Control

in degrees on either side of the dead center mark. When cylinder number one was on dead center, the pointer was placed at the dead center mark on the disc. The pointer was then placed in the high tension ignition circuit and the spark passing from the pointer to the disc indicated accurately the crank position when the spark passed in the cylinder.

(h) Air Preheater. The entering air was heated to any temperature desired by a gas heater which was regulated by controlling the gas burners.

(i) Temperature Readings. All of the lower temperatures such as the inlet air, cooling water, mixture and hygrometer readings were measured with mercurial thermometers accurate to within one degree F. The exhaust gas temperatures were obtained by means of iron-constantin thermocouples. These couples do not have a straight line calibration curve and it was necessary to check the calibration with a platinum-rhodium couple. The calibration was checked at intervals in an electric furnace with the standard couple to insure accuracy. A millivolt meter calibrated in degrees Fahrenheit was used to indicate the temperature, the smallest division on the scale being 10°F. The accuracy of the couples in all cases was 5°F. The bare tips of the couples were placed at the exhaust ports where possible and in the center of the manifold section in other cases. The position of the thermocouples in some of the first tests with Manifold No. 1 is shown in Fig. 15. In these tests one couple registered the temperature of the gases from cylinders one to five while the other couple measured the exhaust temperature from cylinder number six.

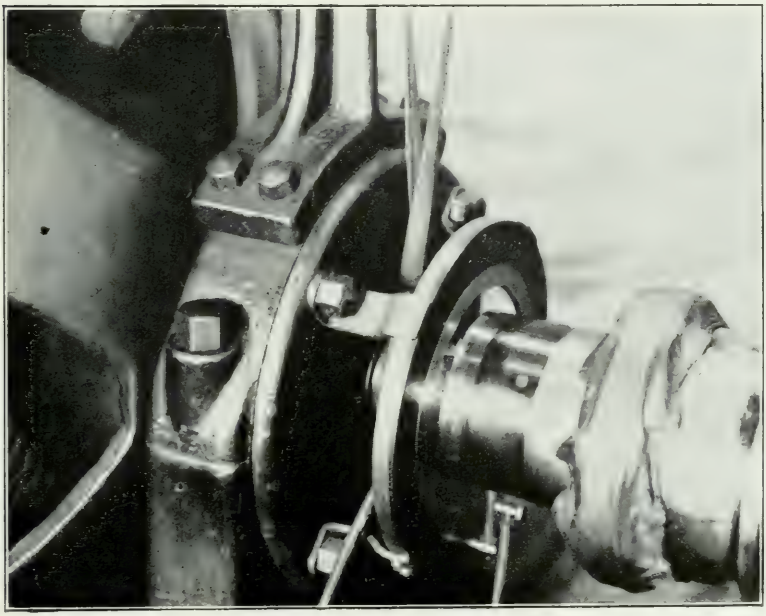

Fig. 14. Ignition Timing Device

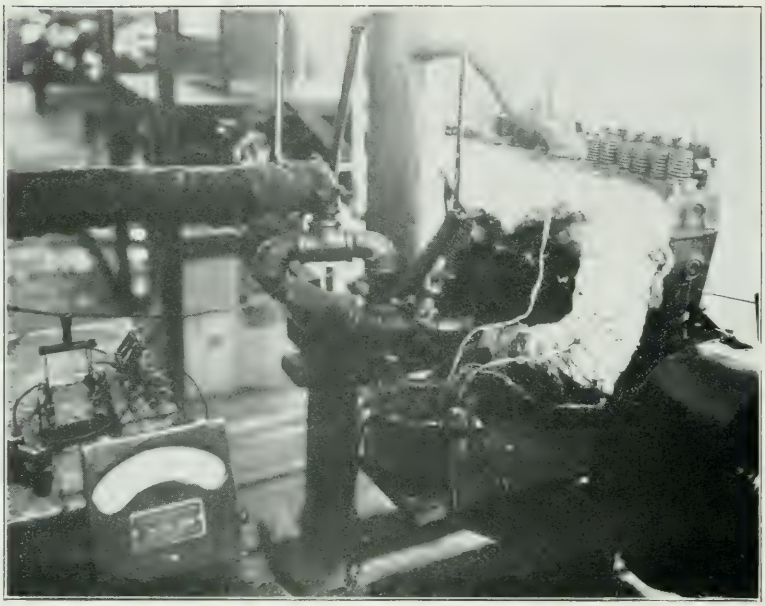

Fig. 15. Thermocouples for Exhaust Gas Temperatures

21. Method of Conducting Tests: In this investigation to show the effects of the temperature of the cooling water and of the inlet air on the temperature of the exhaust, the timing of the ignition and the richness of the fuel mixture, the tests were all run at half load at 1000 r. p. m. All of the running conditions were held constant except the one condition under examination. The engine was allowed to run under test conditions until all of the temperatures had become constant before the test was started. In carrying out the test, the procedure was as follows: The initial readings of the revolution counter and air meter were recorded, the fuel beaker filled and the switch in series with the fuel balance closed. When the beam came to a balance, it closed the circuit which started the stop watch, revolution counter and hand on the dial of air meter, by means of electro-magnets. A weight equal to the fuel to be used was then removed from the scale pan, and when the scales again came to a balance the registering apparatus was electrically stopped. During the run the temperatures of the inlet air, cooling water, pyrometer and hygrometer readings were taken. The speed during the test was kept constant by regulating the field rheostates of the dynamometer. At the end of the test the variable was

changed to another value and when the apparatus warmed to the new condition another test was run. In all cases the tests were made at constant power and not at constant manifold vacuum.

22. Discussion of Results: In reviewing the results obtained in the exhaust gas temperature series, the effect of the five influencing factors on the exhaust gas temperature as outlined in paragraph 18, will be discussed under separate paragraphs. The graphical results Figs. 16 to 28, showing each of the factors investigated are placed as closely as possible to the paragraph relating to the subject under discussion.

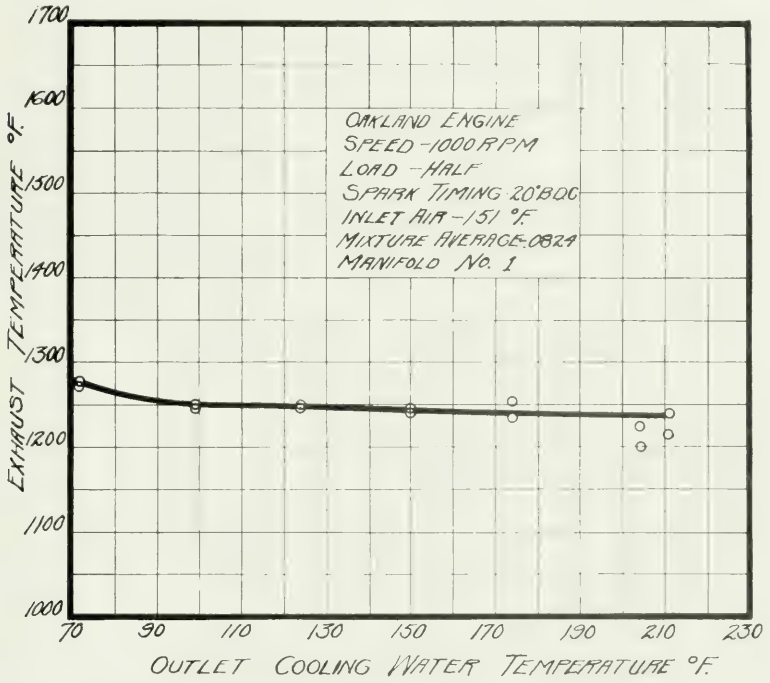

Fig. 16. Cooling Water Temperature and Exhaust Gas Temperatures

23. The Effect of Changing the Cooling Water Temperature: The temperature of the cooling water was varied between 70°F. and 212°F., the test series being run at half load at 1000 r. p. m. The results are graphically represented by the curve in Fig. 16. Contrary to what might have been expected, the tests show the effect of cooling water temperature to have little influence on the exhaust gas temperatures. Increasing the cooling

water temperature from 70°F. to 210°F. decreased the exhaust gases less than 50°F. The series under discussion was run with good carburetion conditions. If the temperatures had not been high enough for good carburetion the slow and irregular burning would be manifested by a larger change in the exhaust temperatures. The deciding factor in determining the temperature of the cooling water should not be carburetion, but rather the actual requirements for the cooling of any part, or the requirements of the lubricating system. In any case the widest variation in cooling water temperature will have almost no effect upon the exhaust temperature provided good carburetion is maintained.

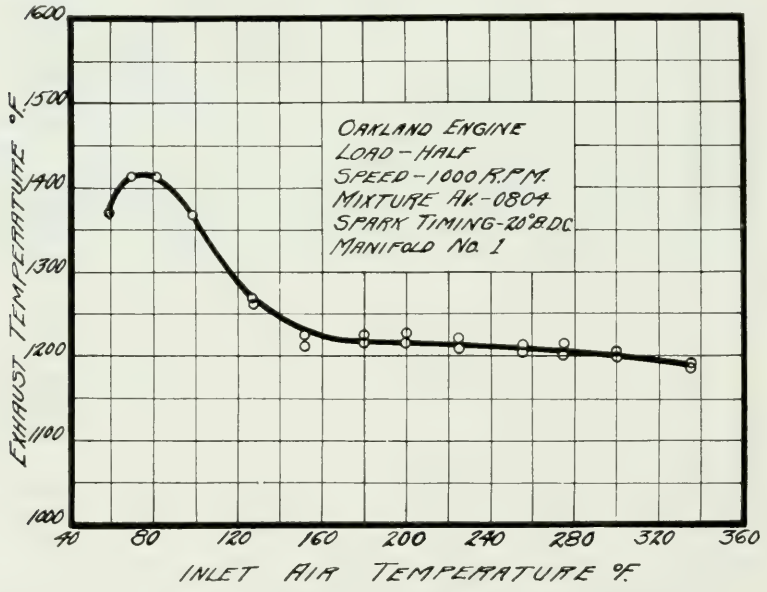

Fig. 17. Inlet Air Temperature and Exhaust Gas Temperatures

24. The Effect of Changing the Inlet Air Temperature: The investigation was made at half load and 1000 r. p. m., the inlet air temperature being varied between 59°F. and 336°F. The results are shown in Fig. 17. The reason for the peculiar shape of the curve with the low inlet temperature is probably as follows: With the 59°F. air, probably all of the fuel did not burn before release. As the temperature increased to about 80°F., the combustion became complete but since it was slow the loss of temperature due to radiation and work were at a minimum, while the exhaust temperatures were a maximum. At temperatures

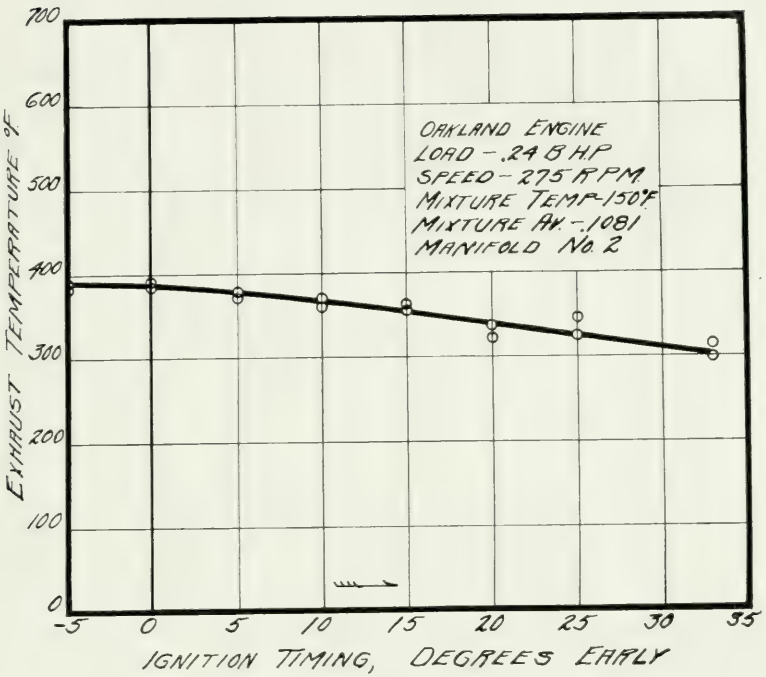

Fig. 18. Effect of Ignition Timing, No Load

between 80°F and 160°F. the vaporization of the fuel improved very rapidly, the combustion becoming more and more rapid, was completed earlier in the stroke and the loss of temperature due to radiation and useful work increased so the exhaust gas temperatures decreased correspondingly. Since an increase in the rate of combustion beyond the point where it was complete at the beginning of the working stroke, would have little effect, the decrease in exhaust temperature with inlet temperatures above 160°F. was not so pronounced. As long as we keep within the bounds of good carburetion temperatures any change in inlet air temperature will have very little effect on the exhaust gas temperature.

25. The Effect of Changing the Ignition Timing: The effect of the spark timing was studied with the engine idling at low speed, Fig. 18; two series at half load, 1000 r. p. m. Figs. 19 and 20, and at full load, 2000 r. p. m. Fig. 21. This covered the extreme operating conditions and proved that in all cases advancing the timing reduced the temperature of the gases. The idling at 275 r. p. m. and developing 0.24 H. P. in all cases, showed

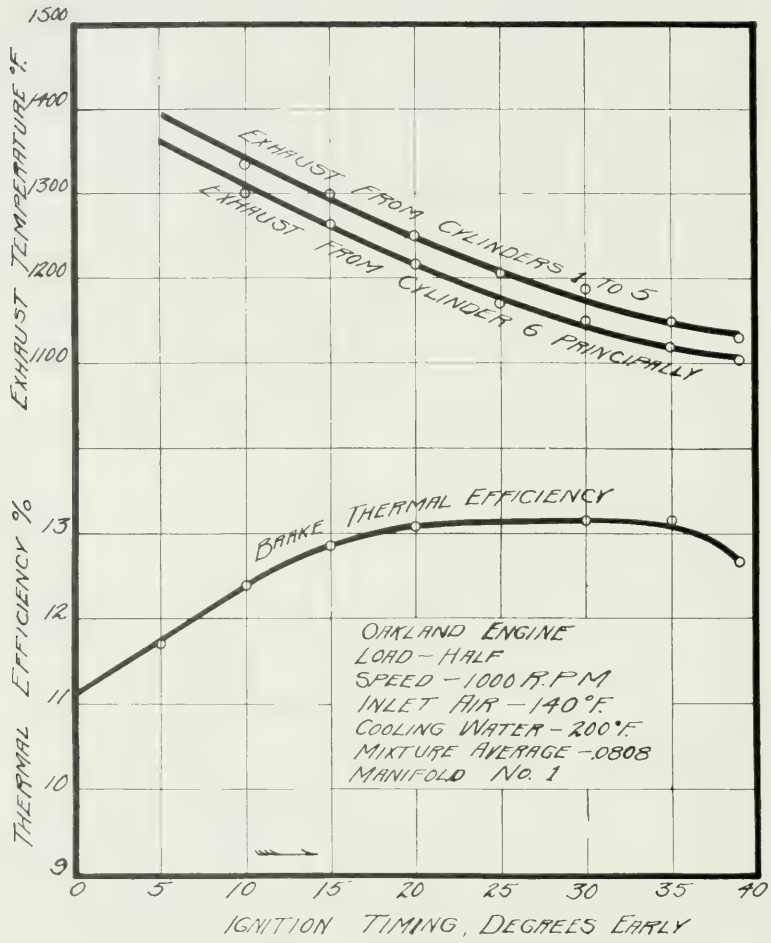

Fig. 19. Effect of Ignition Timing, Half Load

about 90 F. decrease at 33° advance. The half load, 1000 r. p. m. determinations show the same tendencies throughout the range tested. One series was run with a slightly richer mixture and the brake thermal efficiencies are shown in both plots. As would be expected the richer mixture produced the higher temperatures. At 2000 r. p. m. full load, the temperature change seems rather narrow considering the range of timings used. This indicates that to meet the extreme power condition, combustion must be practically complete at the beginning of expansion stroke.

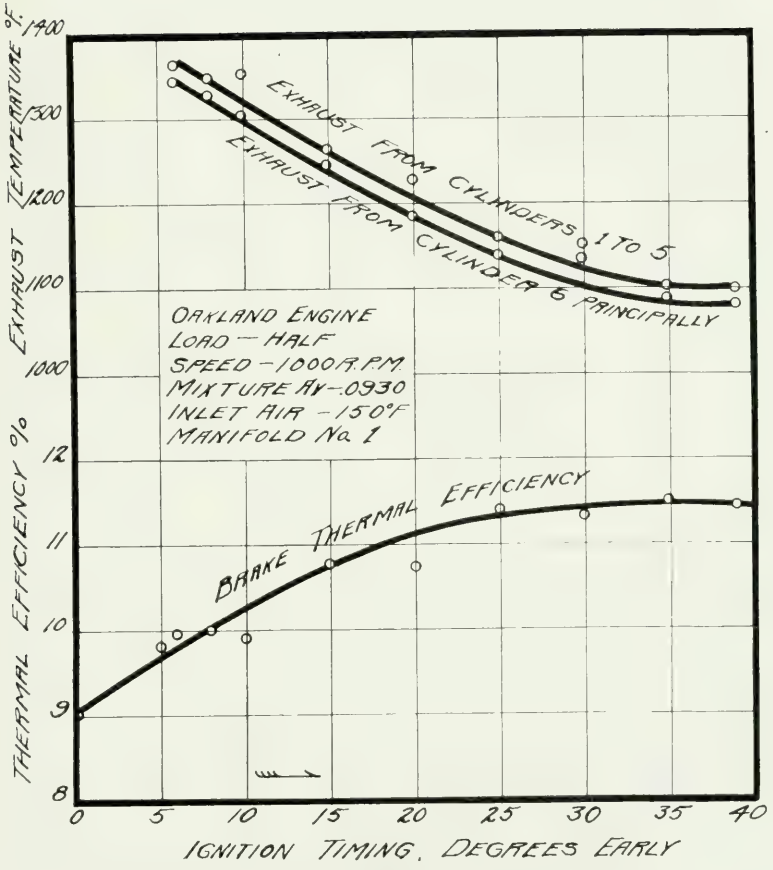

Fig. 20. Effect of Ignition Timing, Half Load

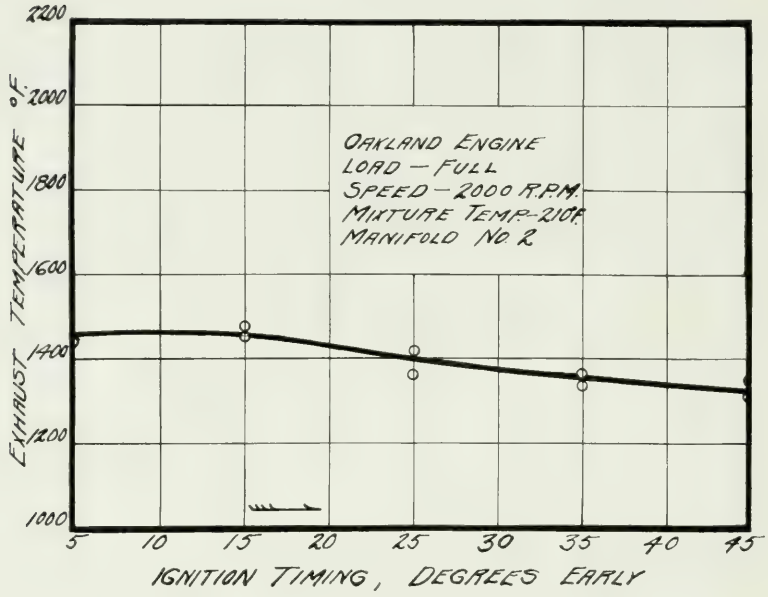

Fig. 21. Effect of Ignition Timing, Full Load

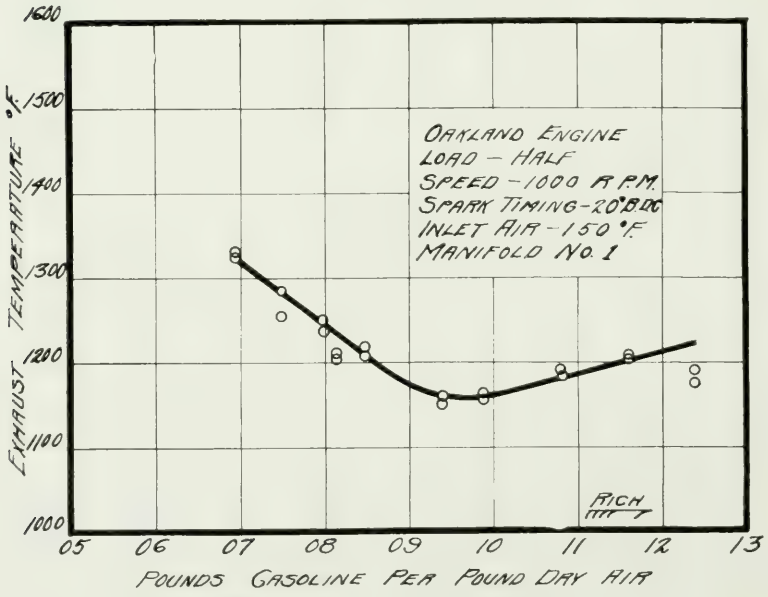

Fig. 22. Mixture Ratio, Half Load, Manifold No. 1

26. The Fuel Mixture: The effect of fuel mixture on the exhaust gas temperature was determined by three test series, two at half load, 1000 r. p. m. and one at low load, low speed. In this group the power was held constant and the mixture varied to ascertain the exhaust temperature effect. Fig. 22 shows the results at half load, using Manifold No. 1. Fig. 23 presents the same series except that Manifold No. 2 is used. When using Manifold No. 1, the intake air was preheated for good performance and in the case of Manifold No. 2 the mixture was heated. Both series show exactly the same results except that the temperature for any one mixture ratio is 200° F. lower when using

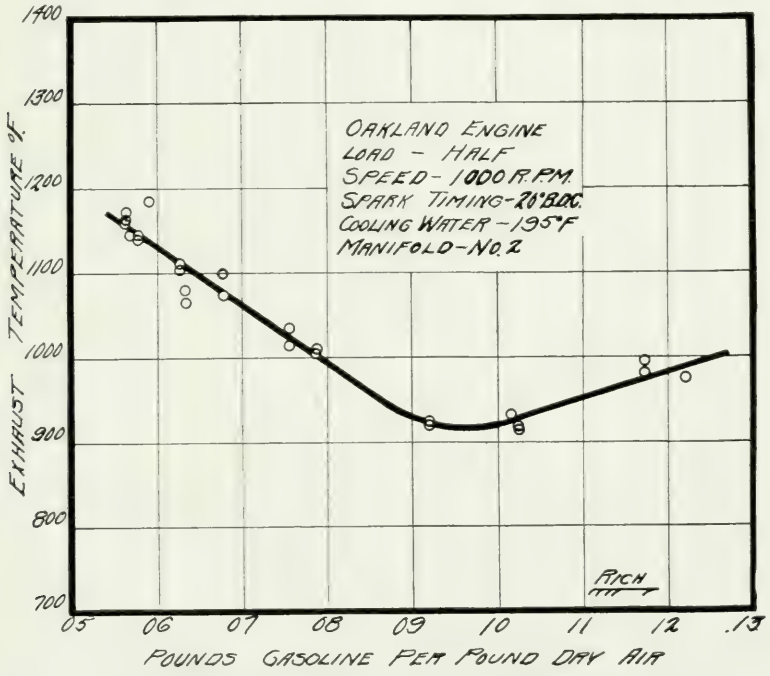

Fig. 23. Mixture Ratio, Half Load, Manifold No. 2

Manifold No. 2. This is caused partly by the use of less heat on the hot spot than in the preheated air and also because the radiation from the exhaust manifold was higher than in the first case because it was not jacketed. The shape of the curve in the idling series, Fig. 24, has a tendency to assume a similiarity to the preceding two. The idling when using Manifold No. 2 is not the best, with respect to mixture distribution, as the exhaust temperature shows. This is especially true at the leaner and high power mixtures. In any case the fuel-air mixture must be adjusted to give good power and high efficiency. It is necessary

to hold the mixture within narrow limits in order to obtain maximum efficiency and thus nearly the maximum exhaust temperature will be maintained.

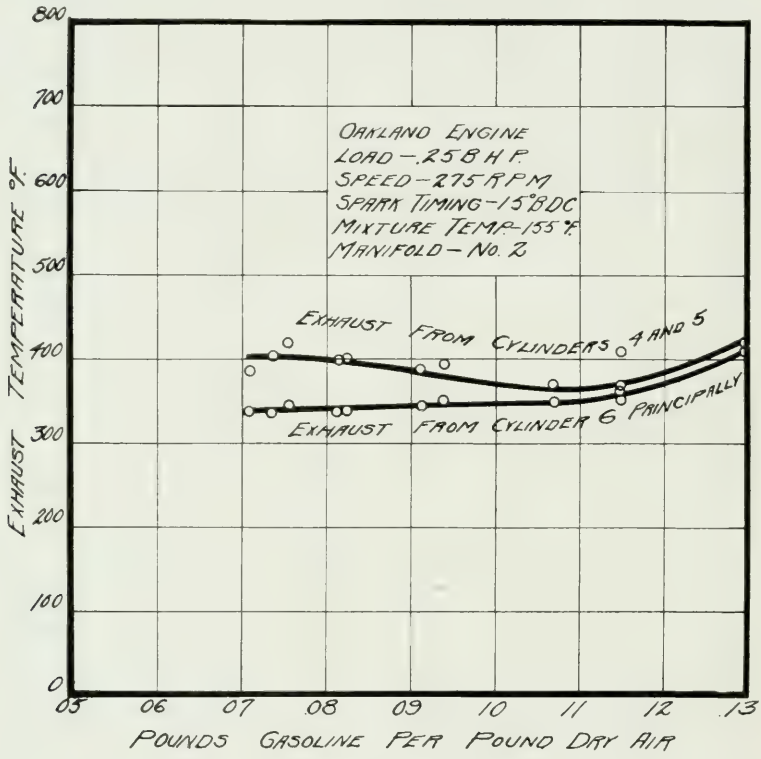

Fig. 21. Mixture Ratio, No Load

27. The Effect of Speed: The effect of speed is shown at three different loads, the revolutions per minute varying from 300 to 2000 r. p. m. Fig. 25 presents the effect at one-tenth load; Fig. 26, at half load, and Fig. 27 at full load. The change of speed in all cases shows a very wide variation in temperature. Two series are shown at full load at slightly different mixture ratios, the second test being the richer and showing the lower temperatures. The maximum temperatures reported in any case are less than 1500° F. The lowest temperatures are, of course, at low speed idling, or 400° F. at 400 r. p. m. The form of the curve shows that the exhaust temperature varies directly as the rate of fuel burned, the increase of mixture flow causing the increase in temperature.

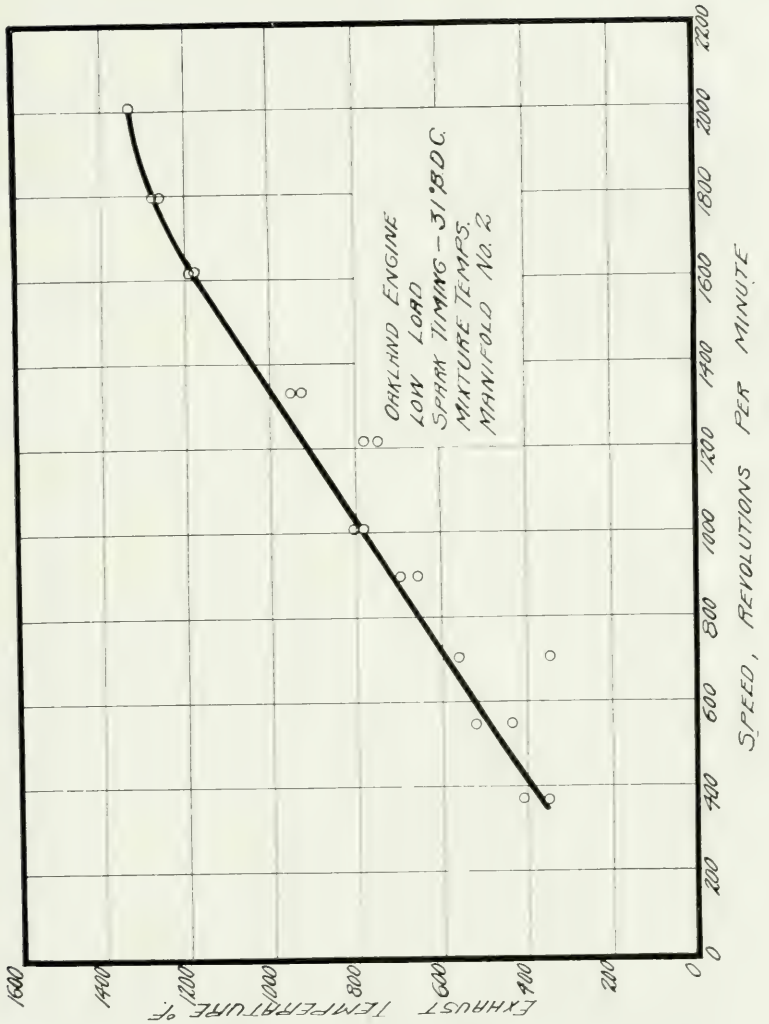

Fig. 25. Effect of Speed, Low Load

28. The Change of Load: The change of exhaust temperature due to load is also shown by the speed series. The data has been replotted in Fig. 28, to show the details. It is noticed that the maximum difference between low and full loads occurs at the lower speeds. For example, the difference is 270°F. at 300 r. p. m. and decreases to 110°F. at 2000 r. p. m.

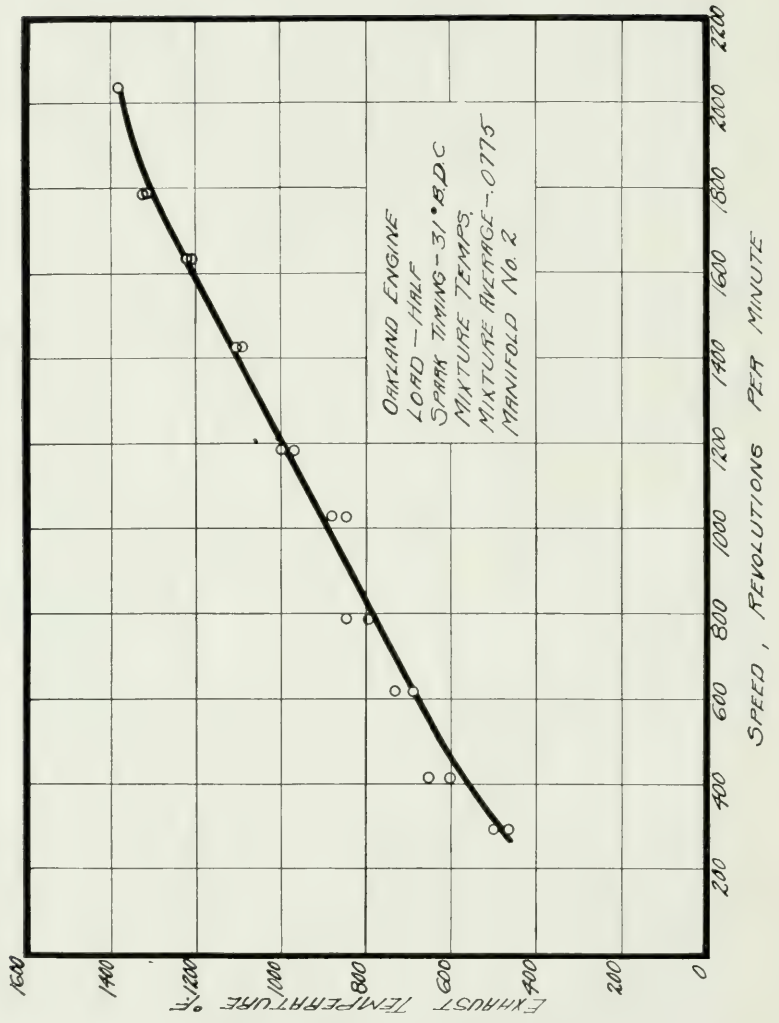

Fig. 26. Effect of Speed, Half Load

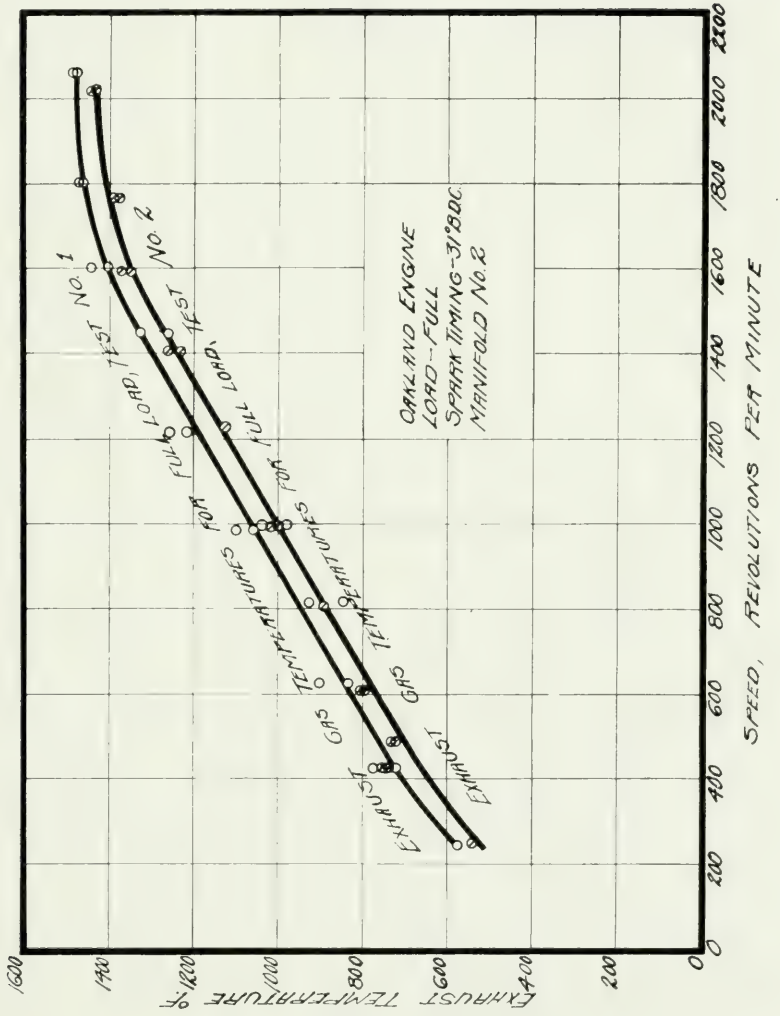

Fig. 27. Effect of Speed, Full Load

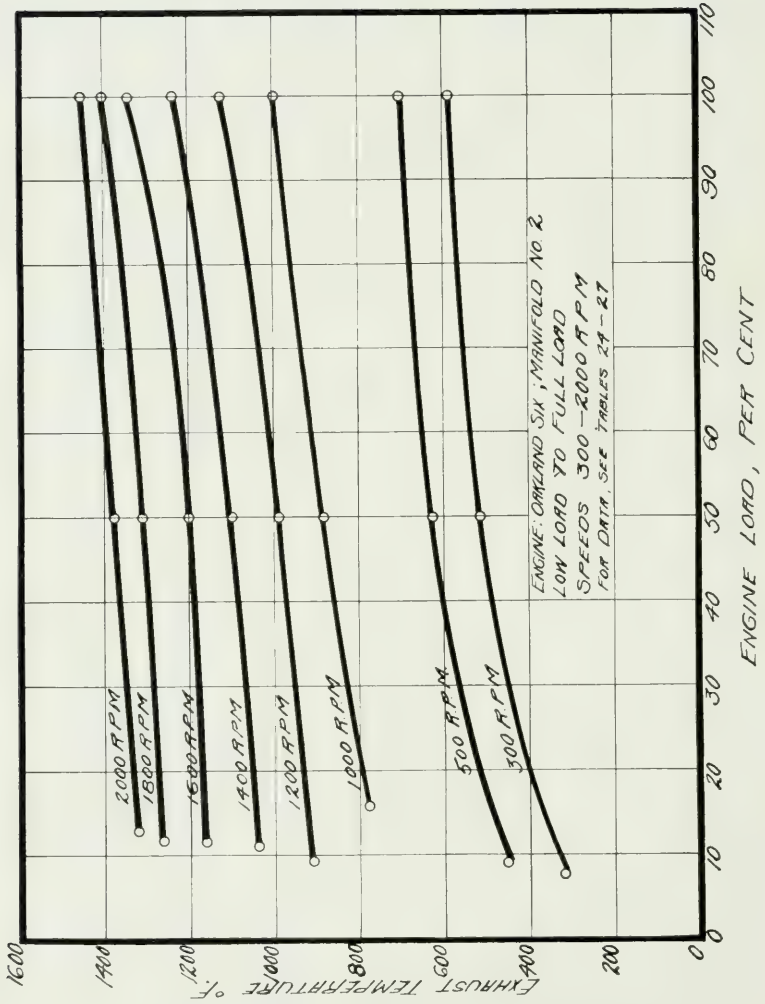

Fig. 28. Summary of Effect of Load and Speed

29. The Range of Temperatures Obtained: The foregoing tests show that the temperature of the exhaust gases from an engine vary through a wide range and depend upon the conditions under which the engine is operating. The minimum temperature is approximately 300° F. as an engine very seldom operates at less than 300 r. p. m. for any length of time. This low temperature occurred with an ignition of 31° advance and so the exhaust temperature would rise as the timing is retarded for regular and even firing. The temperature at the other extreme, full load and maximum speed, seldom attains 1500° F. This occurs at 2000 r. p. m. and judging from the shape of the curve, will be nearly the maximum ever attained at any speed. When an engine is operating under good performance conditions the temperatures are almost always high enough for a well designed manifold to vaporize fuels somewhat less volatile than our present gasoline. In this way producing good distribution, good combustion and comparative freedom from crank case dilution. It is also true, that the low idling speeds of an automobile engine are barely adequate, but when the reserve heat in a manifold is considered, an engine can idle for about fifteen minutes before the mixture temperature is a minimum. If necessary, when using heavier fuels, the lowest speed at idling may be increased slightly to avoid poor vaporization of the fuel. In truck and tractor operation where equipped with governors, the speed maintained should minimize the difficulties.

IV. APPLICATION

30. The Object of the Hot Spot Manifold: Before starting the design of a "hot spot" manifold, it will be well to call to mind the functions of such a manifold. Briefly stated, it is expected to supply sufficient heat to produce even distribution and perfect combustion, and to do it in such a way as to result in the lowest possible mixture temperature. This is to secure the maximum engine power without detonation. The best manifold will be the one that accomplishes these ends, requires no attention and is simple and cheap to manufacture.

31. Manifold Requirements: In practical operation, the condition most difficult to meet is the sudden opening of the throttle after a long period of low speed idling. Under idling conditions the absolute pressure in the intake manifold is very low, lowering the boiling point of the fuel and causing it to vaporize at lower temperatures than under atmospheric pressure. Also during periods of idling the temperature of the metal in the "hot spot" drops to a minimum. The sudden opening of the throttle draws a large quantity of liquid fuel into the manifold at approximately atmospheric pressure. These two conditions both demanding additional heat when occurring simultaneously will, therefore, be the most severe test to which the manifold can

be put. Its ability to vaporize the fuel at atmospheric pressure is, therefore, the crucial one, and if it can do this, it will be able to properly vaporize the fuel under any decreased pressure.

32. Factors Affecting Vaporizing Capacity of a Manifold: In vaporizing fuel the requirements are time, surface and available heat. The case is analogous to that of producing steam in a boiler. Like the water, the fuel has a latent heat of vaporization, and this heat must be brought in from the outside in the proper quantities before the required amount of vapor is produced. The rate at which the vapor is produced will vary directly with the liquid surface that is exposed to the heat, and an increase in the temperature of the source of heat will increase the amount of vaporization per unit area. The vaporizing capacity of a given manifold is a definite thing, and attempts to work it beyond the rated capacity will be unsatisfactory.

33. Time Necessary for Vaporization: There is a law relating to vapor pressures that may be stated as follows: For a given liquid there is a temperature corresponding to every definite pressure of its vapor at which the two will remain in contact unchanged. The liquid tends to maintain this vapor pressure, at this temperature, throwing off vapor as soon as the pressure gets below this point, while a greater pressure than the one at equilibrium cannot be maintained at this temperature.

When the liquid is throwing off its vapor into an atmosphere of low saturation, the rate of vaporization will be rapid so long as the necessary heat is available. As the atmosphere becomes more nearly saturated, the rate of vaporization decreases rapidly. To vaporize a fuel under these conditions requires considerable time, especially when it is necessary to approach complete saturation of the atmosphere as in carburetion. The fuel mixture is drawn through the intake manifold at a very high velocity so that the time allowed the fuel for vaporization in the manifold is very short. Thus, the mixture is of necessity wet, and a large part of the fuel is in liquid form, even when the temperature is high enough to completely vaporize it if proper time were available. This is the reason it is so difficult to produce a dry intake manifold. Likewise, when the fuel is once thoroughly vaporized, it can be mixed with cold air and drawn through a cold manifold before it has time to condense. It requires very much higher temperatures to produce a dry mixture in an intake manifold than it does to keep the mixture dry, when it is once in that state. Similarly, a mixture once dried can be mixed with more cold air and passed through a manifold without depositing any of its fuel, even when the temperatures are much too low to maintain a dry mixture for longer periods of time.

34. Surface: Atomizing the fuel increases the surface exposed to the air and is one of the best ways of increasing the rate of vaporization. Another effective way of producing rapid

vaporization, is to cause a film of liquid fuel to flow over the surface of heated metal. Either can be used in the "hot spot" manifold and may be made very effective. When the rate of vaporization at the temperature used and the fuel consumption rate of the engine are known, the necessary heated surface can be computed.

35. Relation Between Gas Temperature and Fuel Flow: For any engine there is a specific relation between exhaust gas temperature and fuel flow rate. This is shown in Fig. 29 for the engine used. No matter what loads or speeds are used to produce

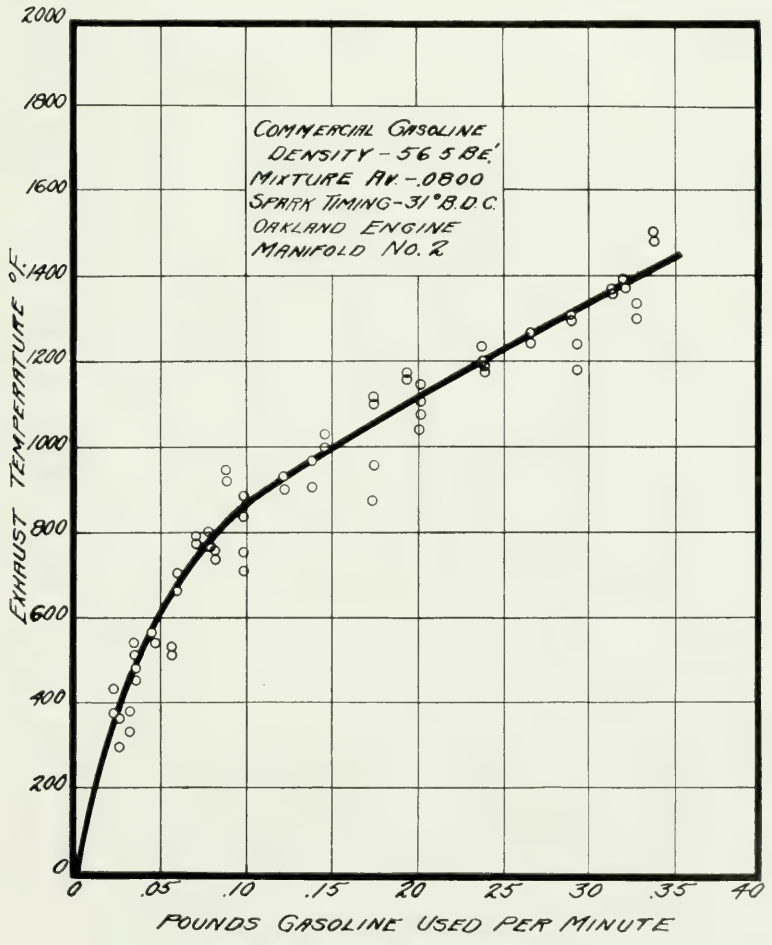

Fig. 29. Effect of Fuel Flow Rate

the flow rate, the relationship is a definite one, providing a constant ignition timing and mixture ratio are used. Values from Fig. 29 can be applied to any engine with a fair degree of accuracy, assuming the volumetric efficiency the same and the piston displacement proportional to the flow rate of the engine in question. The increase of temperature with the flow rate can be compared to the action of a furnace. The more fuel burned, the higher the resulting furnace temperature.

36. Temperature Range Necessary: The tests demonstrate that the temperature necessary for the effective vaporization of the fuel will vary with the different grades of fuels. Where possible the fuel to be used should be tested and a determination made of the lowest temperature in the metal that will maintain the fuel in the "spheroidal" state. Any temperature above this that is not high enough to cause ignition in the manifold may be used. None of the fuels reported in these tests were ignited at less than 1460° F., indicating that the range of permissible temperatures is extremely wide. This makes it possible to design a manifold in which excellent results may be obtained without any close regulation of the temperature of the heated portions. The deposition of solid matter takes place entirely at temperatures below those necessary for the spheroidal state, hence the necessity of keeping above this temperature. There is also a serious mistake very commonly made in the handling of engines using two fuels. The engine is turned over to the heavy fuel before the manifold is hot enough to carburete it properly. This results in waste of fuel, dilution of the lubricating oil and solid deposits on the walls of the intake manifold.

37. Summary of Results:

Part I.

(a) There is a definite range of temperatures for each fuel where deposition of solid matter occurs.

(b) Highest rates of vaporization occur just before the spheroidal state.

(c) The spheroidal state always occurs at temperatures higher than the end point of the fuel.

(d) The vapor is not readily condensed when produced from liquid spheroidal condition.

(e) The rates of vaporization in the spheroidal state are more nearly constant than at lower temperatures.

(f) No deposition of solid matter is present with temperatures sufficient to produce the spheroidal state.

From these considerations it seems very desirable to maintain hot spot temperatures in the spheroidal range.

Part II.

(g) Ordinary temperatures of outlet cooling water have a

negligible effect on exhaust gas temperatures if proper carburetion is effected.

(h) Using 56 Beaume' gasoline, a 160° F. temperature is required for the intake air before proper combustion is insured, as judged by the exhaust temperatures.

(i) An advance of ignition will, in general, decrease the exhaust temperature, the magnitude depending on the load as well as the speed of the engine.

(j) All tests at constant power show minimum exhaust temperatures at mixture ratios slightly richer than the high power ratio.

(k) Exhaust temperature varies directly with engine speed to a maximum at very high speed.

(l) The effect of load on the exhaust temperatures is greatest at the lower speeds.

PART III.

(m) Thermostatic control of vaporizing well is unnecessary as the temperature of the exhaust is insufficient to flash the liquid, if area of well or hot spot is properly designed.

(n) Acceleration after a long period of idling is a more difficult condition to meet than is the idling itself, and indeed is the most severe situation with which the designer has to contend. This is due to the lowered manifold vacuum, increase in fuel flow and lag of exhaust temperatures in hot spot.

(o) Given the engine size, type of fuel used, and exhaust temperature conditions the hot spot area may be computed.

37. GENERAL CONCLUSIONS:

(a) HEAT THE FUEL BUT NOT THE AIR. Effort should be made to heat the fuel without heating the air. There are two main reasons for this. The fuel may thus be vaporized at a very high temperature with a small amount of heat, and this vaporization may be accomplished very rapidly. The dry fuel vapor may then be mixed with cool air and drawn into the cylinder before it has had time to condense and drop out of the mixture. The final mixture may thus be made usably dry at the lowest possible temperature. When the air is allowed to come in contact with the "hot spot", it becomes unnecessarily heated and tends to keep the metal in the "hot spot" at too low a temperature to be most effective in vaporizing the fuel.

(b) IMPROVED CARBURETION DEPENDS UPON IMPROVED MANIFOLDING. In presenting this work the authors wish to call attention to the fact that one of the principal causes of the present poor carburetion lies in the improper manifolding of engines. Not only can our present commercial motor fuels be used with better economy, but even heavier fractions can be properly carburetted by systematically utilizing the heat available in the engine exhaust.

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BULLETIN No. 13. Emergency Braking of Electric Cars, by D. D. Ewing, 1923.

BULLETIN No. 14. Tables of Transmission Line Constants, by D. D. Ewing, 1923.

BULLETIN No. 15. Temperature Requirements of Hot Spot Manifolds, by C. S. Kegerreis and O. C. Berry, 1923.

THE PURDUE ENGINEERING EXPERIMENT STATION

The formal organization of the Engineering Experiment Station of Purdue University was approved by the Board of Trustees on February 28, 1917.

Its function, as set forth at that time, is to conduct researches in the field of engineering, to co-operate with engineering societies in pursuing industrial investigations, and to publish and distribute the results of the work in the form of bulletins.

The board of management consists of the director who is the dean of engineering and the official heads of the four engineering schools.

Bulletins are issued from time to time setting forth the results of scientific investigations conducted in the laboratories of the University by members of the station staff.

Circulars of information containing compilations of facts and data gathered from reliable sources are published as occasion demands.

The co-operation of engineering societies, of public commissions and of individual manufacturers in researches of general interest, will be welcomed by the board of Management.

All communications should be addressed to the

DIRECTOR OF ENGINEERING EXPERIMENT STATION,
Purdue University, Lafayette, Ind.